

**CLAIMS**

We claim:

- 1           1.     A phase shift device, comprising:  
2                     a first superconducting terminal, having a first phase;  
3                     a second superconducting terminal, having a second phase; and  
4                     a phase shifter, coupled to the first superconducting terminal and to the  
5                     second superconducting terminal, wherein  
6                             the phase shifter is capable of causing a predefined difference  
7                             between the first phase and the second phase.
- 1           2.     The phase shift device of claim 1, wherein  
2                     the phase shifter comprises an anisotropic superconductor.
- 1           3.     The phase shift device of claim 2, wherein  
2                     the anisotropic superconductor is a d-wave superconductor.
- 1           4.     The phase shift device of claim 2, wherein  
2                     the first superconducting terminal and the second superconducting  
3                     terminal comprise s-wave superconductors.
- 1           5.     The phase shift device of claim 2, wherein  
2                     the anisotropic superconductor is coupled to the first superconducting  
3                     terminal through a first side; and  
4                     the anisotropic superconductor is coupled to the second  
5                     superconducting terminal through a second side; wherein  
6                             the first side and the second side define a mismatch angle.
- 1           6.     The phase shift device of claim 5, wherein  
2                     the mismatch angle is about 90 degrees.

- 1           7.       The phase shift device of claim 2, wherein  
2                   the phase shifter is electrically coupled to the first superconducting  
3           terminal through a first connector; and  
4                   the phase shifter is electrically coupled to the second superconducting  
5           terminal through a second connector.
- 1           8.       The phase shift device of claim 7, wherein  
2                   the first superconducting terminal, the second superconducting  
3           terminal, the first connector, the second connector, and the phase shifter  
4           overlie a substrate.
- 1           9.       The phase shift device of claim 8, wherein  
2                   the first connector is adjacent to the phase shifter;  
3                   the first superconducting terminal is adjacent to the first connector;  
4                   the second connector is adjacent to the phase shifter; and  
5                   the second superconducting terminal is adjacent to the second  
6           connector.
- 1           10.      The phase shift device of claim 7, wherein  
2                   the first connector and the second connector comprise normal metals.
- 1           11.      The phase shift device of claim 2, wherein  
2                   the length and the width of the first superconducting terminal and the  
3           length and the width of the second superconducting terminal are less than  
4           about 5 microns, wherein  
5                   the first superconducting terminal and the second  
6           superconducting terminal have length and width.
- 1           12.      The phase shift device of claim 2, wherein  
2                   the coupling of the phase shifter and the first superconducting terminal  
3           comprises a first Josephson junction; and

4 the coupling of the phase shifter and the second superconducting  
5 terminal comprises a second Josephson junction.

1 13. The phase shift device of claim 2, wherein

2 the first superconducting terminal and the second superconducting  
3 terminal comprise niobium, aluminum, lead, or tin;

4 the phase shifter comprises  $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ , wherein d has a value  
5 between about 0 and about 0.6; and

6 the first connector and the second connector comprise gold, silver, or  
7 platinum.

1 14. The phase shift device of claim 2, wherein the phase shifter comprises:  
2 a plurality of anisotropic superconductors.

1 15. The phase shift device of claim 14, wherein the phase shifter  
2 comprises:

3 a first anisotropic superconductor; and

4 a second anisotropic superconductor, wherein

5 the first superconductor and the second superconductor are  
6 coupled by a Josephson-junction.

1 16. The phase shift device of claim 15, wherein the Josephson-junction  
2 comprises:

3 a grain boundary.

1 17. The phase shift device of claim 15, wherein

2 the first anisotropic superconductor has a first order parameter with a  
3 first orientation, and

4 the second anisotropic superconductor has a second order parameter  
5 with a second orientation, wherein

6 the first orientation and the second orientation define a  
7 mismatch angle.

1 18. The phase shifter device of claim 17, wherein  
2 the mismatch angle is about 45 degrees.

1 19. The phase shift device of claim 15, wherein  
2 the first anisotropic superconductor and the second anisotropic  
3 superconductor overlie a substrate.

1 20. The phase shift device of claim 19, wherein  
2 the first connector overlies the first anisotropic superconductor; and  
3 the second connector overlies the second anisotropic superconductor.

1 21. The phase shift device of claim 20, wherein  
2 the first superconducting terminal overlies the first connector; and  
3 the second superconducting terminal overlies the second connector.

1 22. The phase shift device of claim 1, wherein the phase shifter comprises:  
2 a ferromagnet.

1 23. The phase shift device of claim 22, wherein  
2 the ferromagnet is an alloy of copper and nickel.

1 24. The phase shift device of claim 22, wherein  
2 the first superconducting terminal overlies a substrate;  
3 the ferromagnet overlies the first superconducting terminal; and  
4 the second superconducting terminal overlies the ferromagnet.

1 25. The phase shift device of claim 24, wherein

2 the second superconducting terminal is isolated from the first  
3 superconducting terminal by an insulator.

1 26. The phase shift device of claim 25, wherein  
2 the insulator is polymethylmethacrylate or  $\text{AlO}_x$ , wherein x is an  
3 integer.

1 27. The phase shift device of claim 24, wherein  
2 the length and width of the first superconducting terminal, the  
3 ferromagnet and the second superconducting terminal, and  
4 the relative position of the first superconducting terminal, the  
5 ferromagnet and the second superconducting terminal is such that they cause a  
6 predefined difference between the first phase and the second phase, wherein  
7 the first superconducting terminal, the ferromagnet and the  
8 second superconducting terminal have a length, a width, and a relative  
9 position.

1 28. The phase shift device of claim 22, wherein  
2 the first superconductor terminal and the second superconductor  
3 terminal are coupled by a junction area; and  
4 the ferromagnet is embedded in the junction area.

1 29. The phase shift device of claim 28, wherein  
2 the length and width of the first superconducting terminal, the  
3 ferromagnet and the second superconducting terminal, and  
4 the relative position of the first superconducting terminal, the  
5 ferromagnet and the second superconducting terminal is such that they cause a  
6 predefined difference between the first phase and the second phase, wherein  
7 the first superconducting terminal, the ferromagnet and the  
8 second superconducting terminal have a length, a width, and a relative  
9 position.

- 1           30.    The phase shift device of claim 1, further comprising:  
2                    a conventional superconducting terminal, coupled to the first  
3                    superconducting terminal by a first junction, and coupled to the second  
4                    superconducting terminal by a second junction,  
5                            the first superconducting terminal, the second superconducting  
6                    terminal, and the conventional superconducting terminal forming a  
7                    loop.
- 1           31.    The phase shift device of claim 30, wherein  
2                    the first and second junctions are c-axis heterojunctions.
- 1           32.    The phase shift device of claim 30, wherein  
2                    the predefined difference between the first phase and the second phase  
3                    is about  $\pi/2$ .
- 1           33.    A phase shift device, comprising:  
2                    a first superconducting terminal means, having a first phase;  
3                    a second superconducting terminal means, having a second phase; and  
4                    a phase shifter means, coupled to the first and second superconducting  
5                    terminal means, capable of causing a predefined difference between the first  
6                    phase and the second phase.
- 1           34.    The phase shift device of claim 33, wherein  
2                    the phase shifter means comprise a d-wave superconductor.
- 1           35.    A phase shifting method, the method comprising:  
2                    providing a first superconducting terminal, having a first phase;  
3                    providing a second superconducting terminal, having a second phase;  
4                    and  
5                            coupling a phase shifter to the first superconducting terminal and to the  
6                    second superconducting terminal, wherein

10032157 1P2101

7 the phase shifter is capable of causing a predefined difference  
8 between the first phase and the second phase.

1 36. The method of claim 35, wherein providing a phase shifter comprises:  
2 providing an anisotropic superconductor.

1 37. The method of claim 35, wherein coupling the phase shifter comprises:  
2 coupling the first superconducting terminal to a first side of the phase  
3 shifter;

4 coupling the second superconducting terminal to a second side of the  
5 phase shifter, wherein

6 the first side and the second side of the phase shifter define a  
7 mismatch angle.

1 38. The method of claim 37, wherein  
2 coupling the first superconducting terminal to the first side of the phase  
3 shifter comprises:

4 coupling the first superconducting terminal to a first connector,  
5 and

6 coupling the first connector to the phase shifter; and

7 coupling the second superconducting terminal to the second side of the  
8 phase shifter comprises:

9 coupling the second superconducting terminal to a second  
10 connector, and

11 coupling the second connector to the phase shifter.

1 39. The method of claim 35, wherein providing the phase shifter  
2 comprises:

3 providing a first anisotropic superconductor, having a first order  
4 parameter with a first orientation, and

5 providing a second anisotropic superconductor, having a second order  
6 parameter with a second orientation, wherein

7 the first orientation and the second orientation define a  
8 mismatch angle.

1 40. The method of claim 35, wherein providing the phase shifter  
2 comprises:

3 coupling the first superconducting terminal and the second  
4 superconducting terminal with a junction; and  
5 providing a ferromagnet in the junction.

1 41. A phase shifter circuitry, comprising:

2 a phase shift device, comprising:

3 a first superconducting terminal, having a first phase;  
4 a second superconducting terminal, having a second phase; and  
5 a phase shifter, coupled to the first superconducting terminal  
6 and to the second superconducting terminal, wherein  
7 the phase shifter is capable of causing a predefined  
8 difference between the first phase and the second phase; and  
9 superconducting circuitry, coupled to the phase shift device.

1 42. The phase shifter circuitry of claim 41, wherein

2 the phase shifter comprises an anisotropic superconductor.

1 43. The phase shifter circuitry of claim 41, wherein

2 the anisotropic superconductor is coupled to the first superconducting  
3 terminal through a first side; and

4 the anisotropic superconductor is coupled to the second  
5 superconducting terminal through a second side; wherein

6 the first side and the second side define a mismatch angle.



- 1           44.     The phase shifter circuitry of claim 41, wherein
- 2                     the phase shifter is electrically coupled to the first superconducting
- 3           terminal through a first connector; and
- 4                     the phase shifter is electrically coupled to the second superconducting
- 5           terminal through a second connector.
- 1           45.     The phase shifter circuitry of claim 41, wherein
- 2                     the first superconducting terminal and the second superconducting
- 3           terminal comprise niobium, aluminum, lead, or tin;
- 4                     the phase shifter comprises  $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ , wherein d has a value
- 5           between about 0 and about 0.6; and
- 6                     the first connector and the second connector comprise gold, silver, or
- 7           platinum.
- 1           46.     The phase shifter circuitry of claim 41, wherein the phase shifter
- 2           comprises:
- 3                     a first anisotropic superconductor, having a first order parameter with a
- 4           first orientation; and
- 5                     a second anisotropic superconductor, having a second order parameter
- 6           with a second orientation, wherein
- 7                     the first orientation and the second orientation define a
- 8           mismatch angle; and
- 9                     the first superconductor and the second superconductor are
- 10           coupled by a Josephson-junction.
- 1           47.     The phase shifter circuitry of claim 41, wherein
- 2                     the first anisotropic superconductor and the second anisotropic
- 3           superconductor overlie a substrate;
- 4                     the first connector overlies the first anisotropic superconductor;
- 5                     the second connector overlies the second anisotropic superconductor;

6 the first superconducting terminal overlies the first connector; and  
7 the second superconducting terminal overlies the second connector.

1 48. The phase shifter circuitry of claim 41, wherein  
2 the first superconducting terminal overlies a substrate;  
3 a ferromagnet overlies the first superconducting terminal; and  
4 the second superconducting terminal overlies the ferromagnet.

1 49. The phase shifter circuitry of claim 48, wherein  
2 the first superconductor terminal and the second superconductor  
3 terminal are coupled by a junction area; and  
4 the ferromagnet is embedded in the junction area.

1 50. The phase shifter circuitry of claim 41, wherein  
2 the phase shift device overlies a substrate;  
3 the superconducting circuitry overlies the phase shift device; and  
4 a first contact terminal and a second contact terminal couples the  
5 superconducting circuitry and the phase shift device.

1 51. The phase shifter circuitry of claim 50, wherein  
2 the substrate is sapphire or  $\text{SrTiO}_3$ .

1 52. The phase shifter circuitry of claim 50, wherein  
2 an insulating layer separates the phase shift device and the  
3 superconducting circuitry, wherein  
4 the first contact terminal and the second contact terminal  
5 couples the superconducting circuitry and the phase shift device  
6 through a first opening and a second opening in the insulating layer,  
7 respectively.

1 53. The phase shifter circuitry of claim 41, wherein

2 the superconducting circuitry overlies a substrate;  
 3 the phase shift device overlies the superconducting circuitry; and  
 4 a first contact terminal and a second contact terminal couples the  
 5 superconducting circuitry and the phase shift device.

1 54. The phase shifter circuitry of claim 53, wherein  
 2 an insulating layer separates the phase shift device and the  
 3 superconducting circuitry, wherein  
 4 the first contact terminal and the second contact terminal couples the  
 5 superconducting circuitry and the phase shift device through a first opening  
 6 and a second opening in the insulating layer, respectively.

1 55. The phase shift circuitry of claim 41, wherein the superconducting  
 2 circuitry comprises:  
 3 quantum computing circuitry.

1 56. A phase shifter circuitry, comprising:  
 2 a phase shift device means, comprising:  
 3 a first superconducting terminal means, having a first phase;  
 4 a second superconducting terminal means, having a second  
 5 phase; and  
 6 a phase shifter means, coupled to the first and second  
 7 superconducting terminal means, capable of causing a predefined  
 8 difference between the first phase and the second phase;  
 9 and  
 10 a superconducting circuitry means, coupled to the phase shifting  
 11 means.

1           57.    A phase shifting method, the method comprising:  
2                providing a phase shift device, comprising:  
3                    providing a first superconducting terminal, having a first phase;  
4                    providing a second superconducting terminal, having a second  
5                    phase; and  
6                    coupling the first superconducting terminal and the second  
7                    superconducting terminal to a phase shifter, wherein  
8                    the phase shifter is capable of causing a predefined  
9                    difference between the first phase and the second phase; and  
10                  coupling a superconducting circuitry to the phase shift device.

1           58.    The method of claim 57, wherein providing a phase shifter comprises:  
2                providing an anisotropic superconductor.

1           59.    A phase shifter chip, comprising:  
2                a plurality of phase shift devices, the phase shift devices individually  
3                comprising:  
4                    a first superconducting terminal, having a first phase;  
5                    a second superconducting terminal, having a second phase; and  
6                    a phase shifter, coupled to the first superconducting terminal  
7                    and to the second superconducting terminal, wherein  
8                    the phase shifter is capable of causing a predefined  
9                    difference between the first phase and the second phase; and  
10                superconducting circuitry, coupled to the plurality of phase shift  
11                devices.

1           60.    The phase shifter chip of claim 59, wherein the phase shifters  
2                individually comprise:  
3                an anisotropic superconductor.

- 1 61. The phase shifter chip of claim 59, wherein  
2 the first superconducting terminals and the second superconducting  
3 terminals comprise niobium, aluminum, lead, or tin; and  
4 the phase shifters individually comprise  $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ , wherein d has a  
5 value between about 0 and about 0.6.
- 1 62. The phase shifter chip of claim 59, wherein the phase shifters  
2 individually comprise:  
3 a first anisotropic superconductor, having a first order parameter with a  
4 first orientation; and  
5 a second anisotropic superconductor, having a second order parameter  
6 with a second orientation, wherein  
7 the first orientation and the second orientation define a  
8 mismatch angle.
- 1 63. The phase shifter chip of claim 62, wherein  
2 the mismatch angle is about 45 degrees.
- 1 64. The phase shifter chip of claim 59, wherein in the individual phase  
2 shifters  
3 the first anisotropic superconductors and the second anisotropic  
4 superconductors are coupled by a Josephson-junction.
- 1 65. The phase shifter chip of claim 64, wherein  
2 the Josephson junctions comprise a grain boundary.
- 1 66. The phase shifter chip of claim 59, wherein in the individual phase  
2 shift devices  
3 the first anisotropic superconductor and the second anisotropic  
4 superconductor overlie a substrate;  
5 the first superconducting terminal overlies the first anisotropic  
6 superconductor; and

7 the second superconducting terminal overlies the second anisotropic  
8 superconductor.

1 67. The phase shifter chip of claim 59, wherein  
2 the plurality of phase shift devices overlie a substrate;  
3 the superconducting circuitry overlies the plurality of phase shift  
4 devices; and  
5 the individual phase shift devices are coupled to the superconducting  
6 circuitry by first contact terminals and second contact terminal.

1 68. The phase shifter chip of claim 67, wherein  
2 an insulating layer separates the plurality of phase shift devices and the  
3 superconducting circuitry, wherein in the individual phase shift devices  
4 the first contact terminal and the second contact terminal  
5 couples the superconducting circuitry and the individual phase shift  
6 device through a first opening and a second opening in the insulating  
7 layer, respectively.

1 69. The phase shifter chip of claim 59, wherein  
2 the superconducting circuitry overlies a substrate;  
3 the plurality of phase shift devices overlie the superconducting circuitry;  
4 and  
5 the individual phase shift devices are coupled to the superconducting  
6 circuitry by first contact terminals and second contact terminals.

1 70. The phase shifter chip of claim 69, wherein  
2 an insulating layer separates the plurality of phase shift devices and the  
3 superconducting circuitry, wherein in the individual phase shift devices  
4 the first contact terminal and the second contact terminal couples the  
5 superconducting circuitry and the individual phase shift device through a first  
6 opening and a second opening in the insulating layer, respectively.

1           71.    The phase shifter chip of claim 59, wherein the superconducting  
2 circuitry comprises:  
3                   quantum computing circuitry.

1           72.    A phase shifter chip, comprising:  
2                   a plurality of phase shift device means, the individual phase shift  
3 devices comprising:  
4                   a first superconducting terminal means, having a first phase;  
5                   a second superconducting terminal means, having a second  
6 phase; and  
7                   a phase shifter means, coupled to the first and second  
8 superconducting terminal means, capable of causing a predefined  
9 difference between the first phase and the second phase; and  
10                  a superconducting circuitry means, coupled to the plurality of phase  
11 shifting means.

1           73.    A method of making a phase shifter chip, the method comprising:  
2                   forming a substrate with a first crystal axis orientation;  
3                   forming a seed layer with a second crystal axis orientation, overlying  
4 the substrate, wherein the second crystal axis orientation is different from the  
5 first crystal axis orientation,  
6                   forming a plurality of openings in the seed layer; and  
7                   forming a plurality of phase shift devices overlying the plurality of  
8 openings.

1           74.    The method of claim 73, wherein the forming of a plurality of phase  
2 shift devices comprises:  
3                   forming a plurality of first anisotropic superconductors over the  
4 plurality of openings; and

5 forming a plurality of second anisotropic superconductors over the  
6 seed layer.

1 75. The method of claim 74, wherein the forming of a plurality of phase  
2 shift devices comprises:

3 forming a plurality of first anisotropic superconductors, having first  
4 order parameters with a first orientation; and

5 forming a plurality of second anisotropic superconductors, having  
6 second order parameters with a second orientation, wherein

7 the first orientation is determined by the first crystal axis  
8 orientation; and

9 the second orientation is determined by the second crystal axis  
10 orientation.